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CHANGE IN MICROSTRUCTURE OF HEAT TREATED TI-6AL-4V ALLOY IN DIFFERENT TEMPERATURES AND STRAIN RATE

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ABSTRACT

Aviation industry is growing day by day and with increase in globalization and growth of overseas trade, it is bound to enhance and develop more on the future. Many more design and manufacturing techniques will need to be changed to improve the operational parameters in aircrafts. These various components of the aircraft engines are manufactured using titanium and the process involved is forging. Forging processes are those manufacturing processes which make use of suitable stresses (like compression, tension, shear or combined stresses) to cause plastic deformation of the materials to produce the required shapes. It may be hot or cold forging processes, which involves heating or striking the material at atmospheric or high temperatures in order to get the desired shapes and sizes. Present research aimed to simulate those hot forging process for titanium alloy at a laboratory level and observe the changes in the microstructure of the titanium alloy with change in temperature and also to then validate the simulation results with a finite element based software, also to observe the effect of friction coefficient between the dies and the sample and their effect on the microstructure. The microstructure is based on the Strain, Strain Rate and Temperature given at the time of the hot forging. These factors need to be varied in order to observe the change in microstructure under different conditions also, to observe the effect of friction coefficient on the microstructure. Once compressed, the sample was sectioned, polished and then viewed under optical Microscope at various zoom levels to observe the changes in the microstructure of the alloy. The Temperature variations and the Force – Stroke graphs obtained from the GLEEBLE 3800 machine during the thermo mechanical compression have been validated using the finite element based software DEFORM 2D.

Keywords: Titanium, Micrographs, strain rate, temperature and simulation.

1.Introduction

Titanium is a metal found in the Periodic table having atomic number of 22 represented as Ti. It is lustrous in nature and has low density, as well as excellent corrosion resistant properties (Bennett et al 2010). Due to non suitability of pure titanium for industrial usage, it is alloyed with various other metals and based on the metals with which it is alloyed and in what percentage, they are classified into various grades each having different set of properties. The alloy that we are working on is Ti-6Al-4V commonly known as Ti-6-4 or Grade 5 of titanium. It has the representation as Ti-6Al-4V which represents that it has 6% Aluminum, 4%Vanadium and small percentage of Iron and Oxygen (total about 0.50%) and rest is titanium. This alloy while retaining the stiffness and thermal properties of the pure titanium alloys, is more stronger than the pure forms. It is a good combination of Strength, corrosion resistance, weld and fabrication ability. Our alloy's initial microstructure after initial heat treatment is of Alpha Type. When an alloy is heated and then annealed, different alloys give different structure. Some give only alpha structure, some only Beta and some Alpha beta structure. The applications of this alloy are many due to its high strength and resistance to corrosion and they are mostly in aircraft turbine parts such as blades, shafts and connections of engines to the wings and the body, engine components, aircraft structural component (C. Huang, et al 2001). All these components are manufactures using techniques of Forging. Forging processes are defined as particular manufacturing processes which make use of suitable stresses (like compression, tension, shear or combined stresses) to cause plastic deformation of

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the materials to produce required shapes. During forging processes no material is removed, i.e. they are deformed and displaced. If done at a lower temperature, then it is called cold forging and if it is done at high temperatures then it is called at hot forging (Leao et al 2005).In order to study the change in microstructure of the alloy when simulated for hot forging, a number of thermo-mechanical (thermo mechanical involves heating the sample before compressing it) tests had been performed on the alloy samples in GLEEBLE 3800 machine (Hi Du 2005).This forging simulation is based on the Strain, Strain Rate and Temperature given at the time of the test. These factors were varied in order to get the desired results.

2. Experimental Work

The thermo mechanical compression of the samples at various temperatures was done in Gleeble 3800 Machine. The Gleeble 3800 has a direct resistance heating system that can heat specimens at rates of up to 10,000°C/second, or can hold steady-state equilibrium temperatures (Lee et al. 2006). High thermal conductivity grips hold the specimen, making the Gleeble 3800 capable of high cooling rates. An optional quench system can achieve cooling rates in excess of 10,000°C/second at the specimen surface2.2 Dry sliding wear test and SEM

Table 1. Material sample test on Gleebe machine

Sample No.	Sample type	Sample Temperature	Soaking time in min.	Strain rate	Type of cooling	Initial length in mm	Final Length in mm
1	950HT-Ti6Al4 V	800°C	5	0.1	Air coolingg	15	6
2	950HT-Ti6Al4V	900°C	5 s	0.1	Air cooling	15	6
3	950HT-Ti6Al4V	1000°C	5	0.1	Air cooling	15	6

2.1 Metal Micrographs

After the completion of the Gleeble compression test, the work piece now in compressed form needs to be analyzed for the changes that have taken place in the microstructure of the component. The procedure may be discuss as- Sectioning the sample: The material is circular in shape after compression, hence sectioned from the middle and two axis-symmetric cut sections obtained. Mounting the sample: Next, a mount is prepared of the cut section of the sample for it to be polished, viewed under the microscope. Polishing the sample: The mounted sample was put on polishing machine and then polished using various grades of polishing papers. Etching process: After obtaining mirror finish in sample after polishing, the sample is dipped in the etching solution for few seconds and then blow dried. After that the sample is again dried and then it can be viewed under the optical microscope at different levels of zoom, namely 5x, 10x, 20x, 50x and 100x.

2.2 Simulation work

DEFORM 2D software was used to validate the results obtained by experimental work in the Gleeble 3800 machine (Kuppan, P 2008). The simulation conditions were created in the software and the resulting Stroke Vs Force diagrams were compared from both the software and the experimental data. In the software the upper die was moved at Strain rate of 0.1 (Table 2) and for that the Stroke Vs Time values were obtained from the formula as below strain rate is given as the units mm/sec hence it can be assumed to be the velocity with which the top die is moving.

Table 2. Strain rate Vs Temp.

S. No	Strain rate	Min.Temp.°C (DEFORM 2D)	Max Temp. °C (DEFORM 2D)	Amount Compressed	Min.Temp.°C (Gleeble)	Max Temp. °C (Gleeble)
1	0.1	814	821	9 mm i.e 60%	791	820

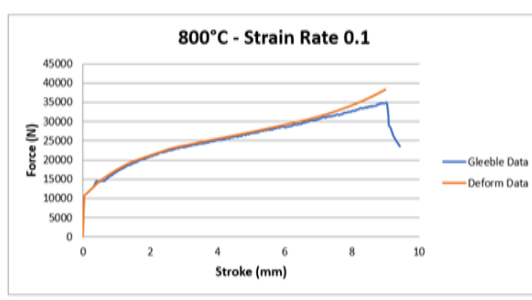

Fig. 1 Force vs stroke for the strain rate 0.1 at 800 ^{o}C.

In the above Fig. 1 the graph containing Gleeble data and Deform data has been plotted for 950°C Heat treated sample which was heated at 800°C and then compressed at strain rate of 0.1. Similarly the graphs were plotted at 900°C, 1000°C.Also simulations were done for observing the effect of friction coefficient between the dies and the workpiece on the microstructure having 100X magnification, of the resulting compressed sample. The sample of 950 °C heat treated hot forged at 800 °C was considered. One set was normal simulations and with friction coefficient and other was used without any friction coefficient.

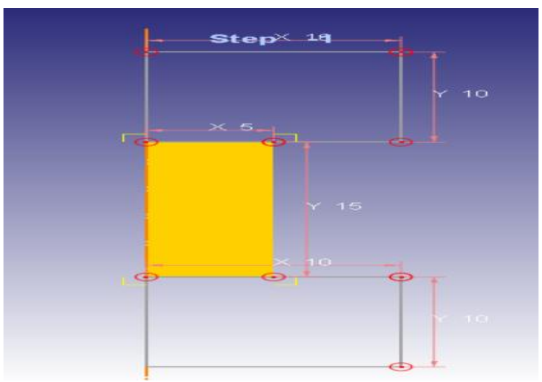

Fig.2 Initial sample- Height15MM, width 5MM(2D)

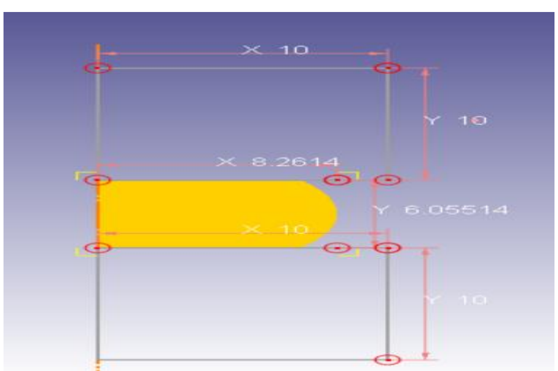

Fig.3: Final sample -Height 6MM, Width 8.26MM (2D)

The values for comparative purpose have been taken on Location 1 (L1), Location 2(L2), Location 3 (L3), Location 4 (L4) as shown in the figure below. The simulations were done for two sets of parameters. One set was normal simulations and another simulation was done by considering the high value of friction coefficient whereas previous simulation is being done without any friction coefficient. Purpose of simulation analysis is to find the adequate variation in friction coefficient and the corresponding values of stress, strain according to temperature at different locations has been shown in Fig.4 & Fig.5 for a sample at 800°C. The values for comparative purpose have been taken on Location 1 (L1), Location 2(L2), Location 3 (L3), Location 4 (L4) as shown in the Fig.4 & Fig.5 above.

Table 3. Different condition of stress, strain and temperature as per the locations at coefficient of friction (μ).

Parameter μ	Stress (Mpa)				Strain				Temperature (°C)			
	Loc 1	Loc 2	Loc 3	Loc 4	Loc 1	Loc 2	Loc 3	Loc 4	Loc 1	Loc 2	Loc 3	Loc 4
0.0	481.25	490.9	495.73	490.0	0.911	0.855	0.98	0.9	1090	1070	1090	1080
0.3	329.56	535.74	548.13	652.26	2.66	0.627	0.931	0.022	1410	1010	800	812

The above table 3, shows the values of Stress, Strain, Temperature at various locations of the sample at friction coefficient of 0 and 0.3.

3. Results and Discussion

The Stress Vs Strain values that are obtained during the experimental work from the gleeble data have been plotted in the graph and the values obtained are as follows:

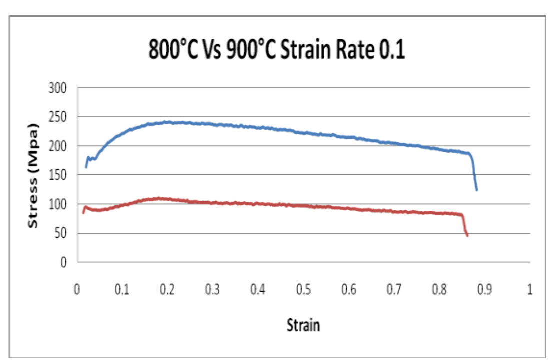

Fig. 6 Stress strain relation for the sample at given temperature conditions

From the above Fig 6, it is visibly clear that the stress values are decreasing with increase in temperature. This has been due to the fact that both plastic deformation and frictional work contribute to heat generation in metal forming. The temperature rise in the specimen that occurs due to the conversion of mechanical energy to heat energy can be responsible for softening during material testing as the strength of a material is temperature dependant, an increase in temperature normally corresponding to a lower strength and hence a lower value of stress is obtained.

3.1 Micrographs

The various sample's micrograph were taken at various locations as shown in Fig 7 and Fig. 8, below and based on these location the micrographs were analysed and the changes observed.

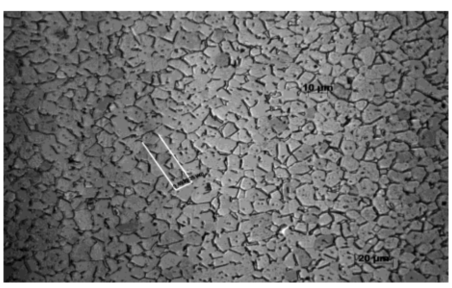

Fig.7 950°C Heat Treated, 800°C Temp, 0.1 Strain rate. (L1*50 zoom, X100magnification)

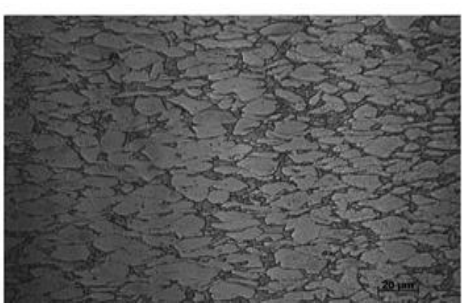

Fig.8 Micrograph of original 850°Heat treated sample(L1*50 zoom, X100magnification)

The Fig. 9 and Fig. 10 shows the micrograph of the original 850 heat treated sample. The grain size in this sample is around 9 to 10 microns. The initial sample was heated in the muffle furnace at 850°C for 5 hours and then furnace cooled. The various micrographs were studied and it was observed that most prominent changes in microstructure was visible at location 1 and location 2. There were least changes observed in Fig. 9 and Fig. 10.and hence the micrographs of Fig. 7 and Fig.8are slitely more rough.

Fig. 9 950° C Heat Treated, 900° C Temp, 0.1 Strain rate. (L1*50 zoom, X100magnification)

Fig. 10 950° C Heat Treated, 1000° C Temp, 0.1 Strain rate. (L1*50 zoom, X100magnification)

4. Conclusion

It is verdict that present sample material having zero friction coefficient is uniformly compressed at uniform temperature distribution, uniform stress distribution and uniform strain. In actual forging process, the friction coefficient cannot be considered as zero and hence due to effect of friction between the compressing die and the workpiece, these are creation of bulge and moreover as the simulation data suggests the distribution of various factors are not uniform. The microstructure of titanium alloy is very sensitive and is dependent on namely three factors and that are strain, strain rate and temperature. Even if we keep the strain rate and temperature constant, there will be non uniform distribution of stress and temperature found due to friction coefficient variation and hence there will be a difference in the grain structure present at various locations which can be proved by the simulation and micrographs. It is due to the experimental conditions which may not be expected as free of coefficient of friction. Also from the above experiments and simulations it can be concluded that the default grain size, increases with increase in temperature and after a certain temperature, it undergoes a change in its microstructure. At temperature near and above 1000 degrees the microstructure begins to change to lamellar structure from the equiaxed one and if the temperature goes beyond 1050 degrees or more the complete transition to alpha phase takes place. At the center and towards the periphery of the workpiece the maximum effect of compression is visible, while on the corners and top the effect visible is less. Hence it can be concluded that there is variation in the values of temperature, stress, strain rate at various locations of the sample and hence due to which various types of microstructures at various locations present which is not desire. Hence maximum efforts must be made to reduce the friction between the dies and the workpiece so that most optimum microstructure may obtained. The simulation and experiment was completed successfully and desirable results were obtained.

References

1. *Bennett C J, Leen S B, Williams E J, Shipway P H and Hyde T H (2010) "A critical analysis of plastic flow behaviour in axisymmetric isothermal and Gleeble compression testing",. Computational Materials Science, Vol.50 ,125-137.*
2. *Huang C, Yamabe-Mitarai Y and Harada H "Iridium-based refractory superalloys by pulse electric current sintering process: Part 1. Elemental powder", Journal of Materials Engineering and Performance, December 2001, Vol. 10(6), 710–717.*
3. *Du H L, Datta P K, Lewis D B and Burnell Gray J S (1994), "Air oxidation behaviour of Ti6Al4V alloy between 650 and 850°", Corrosion Science, Vol.36(4), 631-642.*
4. *Ig1essis J, Frantz C and Gantois M (1978), Memoires Scientifique de la Revue de Metallurgie, Vol.74, 93.*
5. *Leao N F, Pashby I R, Cuttell M and Lord P (2005) "Optimisation of EDM fast hole drilling through evaluation of dielectric and electrode materials", In Proceedings of COBEM, Vol.18, 6-11.*
6. *Lee H T, Mayer J, Hsu F C , Rehbach W P, Weirich T and Dimyati A (2006) "Application of EDM Hole-Drilling Method to the Measurement of Residual Stress in Tool and Carbon Steels",Contributed by the Materials Division of ASME for publication in the Journal of Engineering Materials and Technology, Vol. 128, 468.*
7. *Kuppan P, Rajadurai A and Narayanan S (2008)'Influence of EDM process parameters in deep hole drilling of Inconel 718", The International Journal of Advanced Manufacturing Technology, Vol. 38, 74–84.*

